FINAL REPORT

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NEW YORK UNIVERSITY
FACULTY OF ARTS AND SCIENCE
DEPARTMENT OF APPLIED SCIENCE
New York, NY. 10003

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THE CORRELATION BETWEEN SUNSPOTS AND SOLAR IRRADIANCE

Allan Frei

Dr. Martin Hoffert

Zun-Yan Wang

Principal Investigator: Dr. M. Hoffert

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I. INTRODUCTION

Historicallv, associations have been observed between sunspots and solar activity, and between sunspots and climate. The most obvious example of a possible correlation is the coincidence of the Maunder minimum [Eddy 1976], which was an approximately seventy year period (1645-1715) with scarcely any sunspots, and the "little ice age", a relatively cold period in Europe (for historic sunspot data, see [Eddy 1980]). Although the positive correlation is harder to quantify than the actual existence of the Maunder minimum itself, other evidence support the idea. Greenland ice core temperature data [Schove 1983], auroral numbers [Schove 1983], carbon fourteen data in trees, and historic accounts of coronal activity during eclipses all reinforce the conclusion that: (1) periods of increased sunspot observations correspond to increased solar activity and increased terrestrial temperatures (ie. the "Medieval Climatic optimum" of the eleventh to thirteenth centuries); and (2) periods of fewer sunspot observations correspond to decreased solar activity and lower terrestrial temperatures (ie. the "little ice age", the early twentieth century). Eddy [1976] gives a very interesting discussion of the historical evidence.

Langley [see Newkirk 1983], in the late nineteenth century, attempted to measure solar irradiance over an extended period of time in order to detect changes. The problem with this and other early attempts was that ground based measurements are not sufficiently accurate to measure solar irradiance fluctuations, which are on the order of 0.1%. It was not until the Active Cavity Radiometer Irradiance Monitor (ACRIM) experiment on the NASA Solar Maximum Mission (SMM) was launched in 1980 that continuous data with precision 0.1% was available [Willson, et al 1981].

Willson [Willson et al. 1981] and Hoyt and Eddy [1983] concluded that over timescales of days, solar irradiance is inversely correlated to sunspot activity: an increase in daily sunspot activity caused a decrease in solar irradiance. Their observations

are consistant with current theories, in which energy blocked by sunspots is temporarily stored in the convective zone.

Energy, temporarily blocked, should eventually be radiated by the sun. According to mixing length theory the properties of convective cells at a given depth are characterized by the parameter $a=w/H$, where w is the mixing length and H is the pressure scale height. Current theories predict a thermal relaxation time in the convective zone of about 10^5 years [see Newkirk 1983]. If this is true, then the inverse correlation between sunspots and solar irradiance may carry over into yearly timescales.

However, perturbations of solar thermal and magnetic structures associated with sunspots are still relatively poorly understood. The depth of temperature perturbations due to sunspots, and the propagation rate of these perterbations are unknown. If large scale eddies exist, the convective thermal relaxation time might be much shorter than 10^5 years. If the blocked energy is re-radiated over yearly timescales, then, over this timescale, no correlation would exist. Historical terrestrial temperatures, however, and recent solar irradiance data, suggest the possibility of a positive correlation. In any case, the long term relationship between sunspots and solar irradiance is unknown.

Here, we consider the correlation between the number of sunspot groups and solar irradiance over monthly timescales. At the outset of these calculations, we believed that we might find a positive correlation between these two time series, which would add weight to the theory that turbulence-induced sunspots, over timescales greater than days, increase solar irradiance. We found no correlation at all between the number of sunspot groups and solar irradiance over monthly timescales.

II. DATA

Monthly averaged sunspot data (covering the period from January, 1980 until December, 1984) was obtained from the High Altitude Observatory at the National Center for Atmospheric Research in Colorado. In fig 1 we have plotted the monthly averaged number of daily sunspot groups. Daily ACRIM/SMM data (covering the same period), which we converted to monthly averages, was obtained from Professor Willson at JPL (see fig 2).

III. DATA ANALYSIS

In fig 3 we plotted the monthly averaged solar irradiance against the monthly averaged number of daily sunspots. The data appears to be randomly scattered. In fact, we calculated a regression line through the data using the least squares best fit method. The standard deviation about the regression line was SD = 0.556 (quite large considering that the entire interval of irradiance is 3.0), and the percent of variation in irradiance which could be predicted by a linear fit was only $R^2 = 16.1\%$. This suggests that, over monthly timescales, irradiance is not a linear function of the number of daily sunspot groups.

We also calculated cross correlation coefficients, R, which compare the deviations about the means in the two time series. A value of R = +1 implies that the relative magnitudes and the signs of deviations in one time series about its mean value can be used to exactly predict the behavior of the second time series; a value of R = -1 implies that deviations in one data set correspond in relative magnitude, but are opposite in sign, to deviations in the other data set. One can predict the behavior of one time series according to the behavior of the second time series with a confidence level of $(R^2 X100)\%$. We introduce the variable k, which is a time lag. $[R(k)]^2$ is the confidence level with which we can predict the behavior of one time series at time t according to the behavior of a second time series at time t+k.

In fig 4 we see correlation coefficients of our two time series for various time lags. We can predict the fluctuation in solar irradiance by the number of daily sunspots with a confidence of only $(R^2 X100) <= 25\%$. This is a low correlation. Yet, one interesting feature of the figure is immediately apparent: correlation coefficients for all lag times are positive, and form a very smooth function. This suggests some similarity between the two data sets. Actually, this occurs as a result of similarities in the long term, or yearly, trends, not in the monthly fluctua-

tions. The yearly trends are important, and we shall discuss them. For now, though, we shall eliminate the yearly trend from the data in order to more accurately correlate the monthly fluctuations.

To eliminate the yearly trend, we subtracted the five month running mean from both time series, and correlated, in effect, deviations from the local five month running means. The results, plotted in fig 5, substantiate our previous result. Monthly fluctuations in solar irradiance can be predicted by monthly fluctuations in sunspot-group frequency with a confidence level of only (R^2X100) <= 0.04%. The two time series do not seem to be correlated over monthly timescales.

Over yearly timescales, however, there seem to be similarities. It is important to realize that with only five years of data, no conclusions can be drawn. However, if yearly averages are considered, then from 1980 through 1984: (1) both the solar irradiance and the average number of daily sunspot-group time series are monotonically decreasing; (2) the 1980 and 1981 values are above the mean, and the 1983 and 1984 values are below the mean in both cases. The long term trends appear to be similar. Again, we emphasize that too few data points are available to make a yearly correlation: we mention these issues for purely speculative purposes.

V. CONCLUSION

From Willson [1981], and Hoyt and Eddy [1983] we know that over daily timescales solar irradiance and sunspot activity are inversely correlated. By this we mean that sunspots cause a decrease in solar irradiance.

We investigated the relationship between irradiance and sunspot groups over monthly timescales. Simple statistical methods (ie. linear regression, and correlation coefficients) reveal no correlation between the monthly averaged data sets. This leads us to conclude that over monthly timescales, the number of sunspot groups and the solar constant seem to be unrelated phenomenon.

The problem of correlating sunspots and irradiance over longer timescales has yet to be resolved. Although five data points are insufficient to make a statistical correlation, the trend seems to show a positive correlation. Woodard and Noyes [1985] point out activity-related changes in the solar radius, possibly due to variations in the convective zone (ie. the shrinkage of granulations cells, and dynamo generation of magnetic fields), which would affect luminosity and explain the correlation. If the trend continues over the next sunspot cycle, and the physical mechanism is understood more thoroughly, we might conclude that over yearly timescales increased sunspot activity is associated with increased solar irradiance.

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Fig. 1

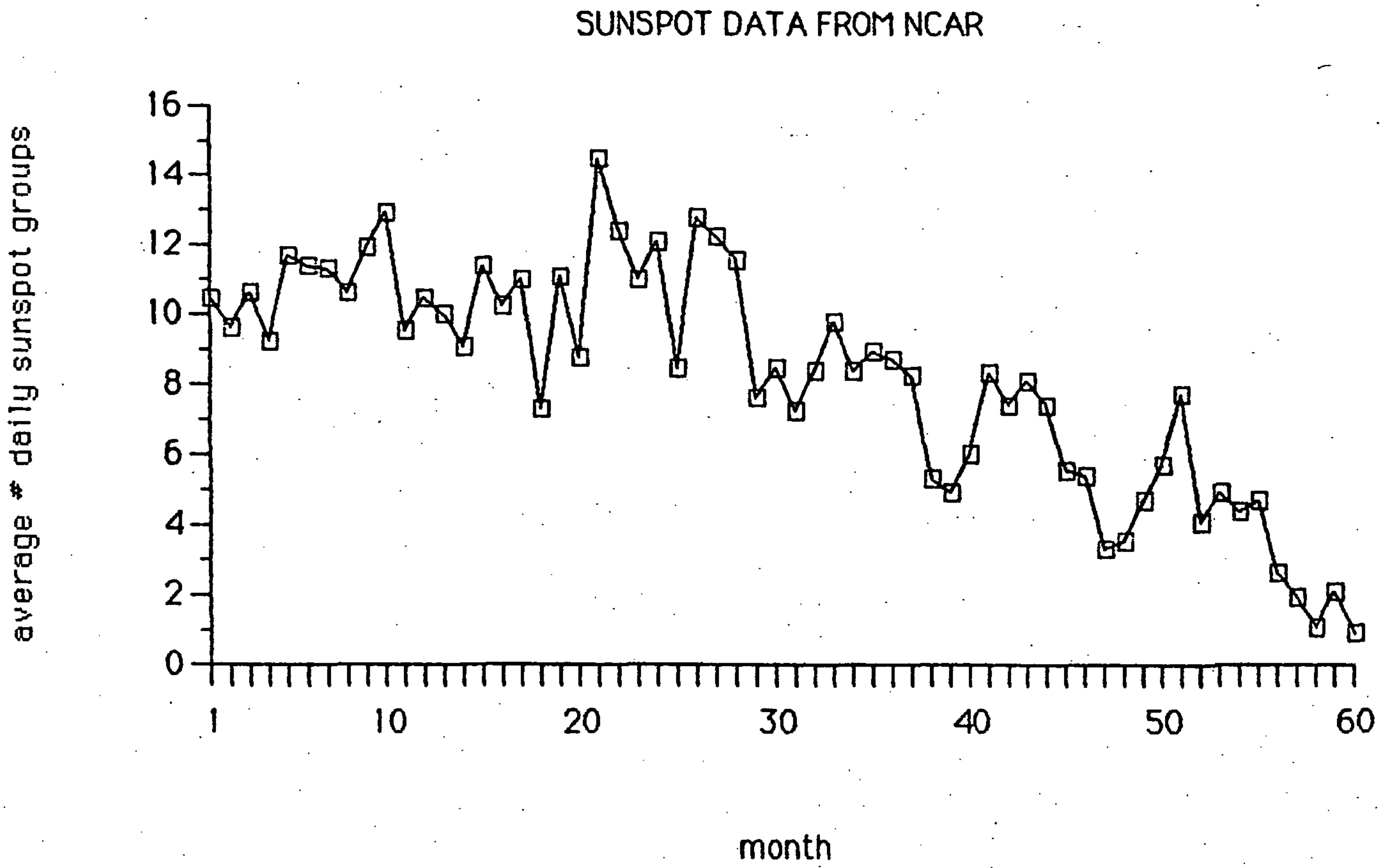

SUNSPOT DATA FROM NCAR
average # daily sunspot groups
0
2
4
6
8
10
12
14
16
1
10
20
30
40
50
60
month

Fig. 2

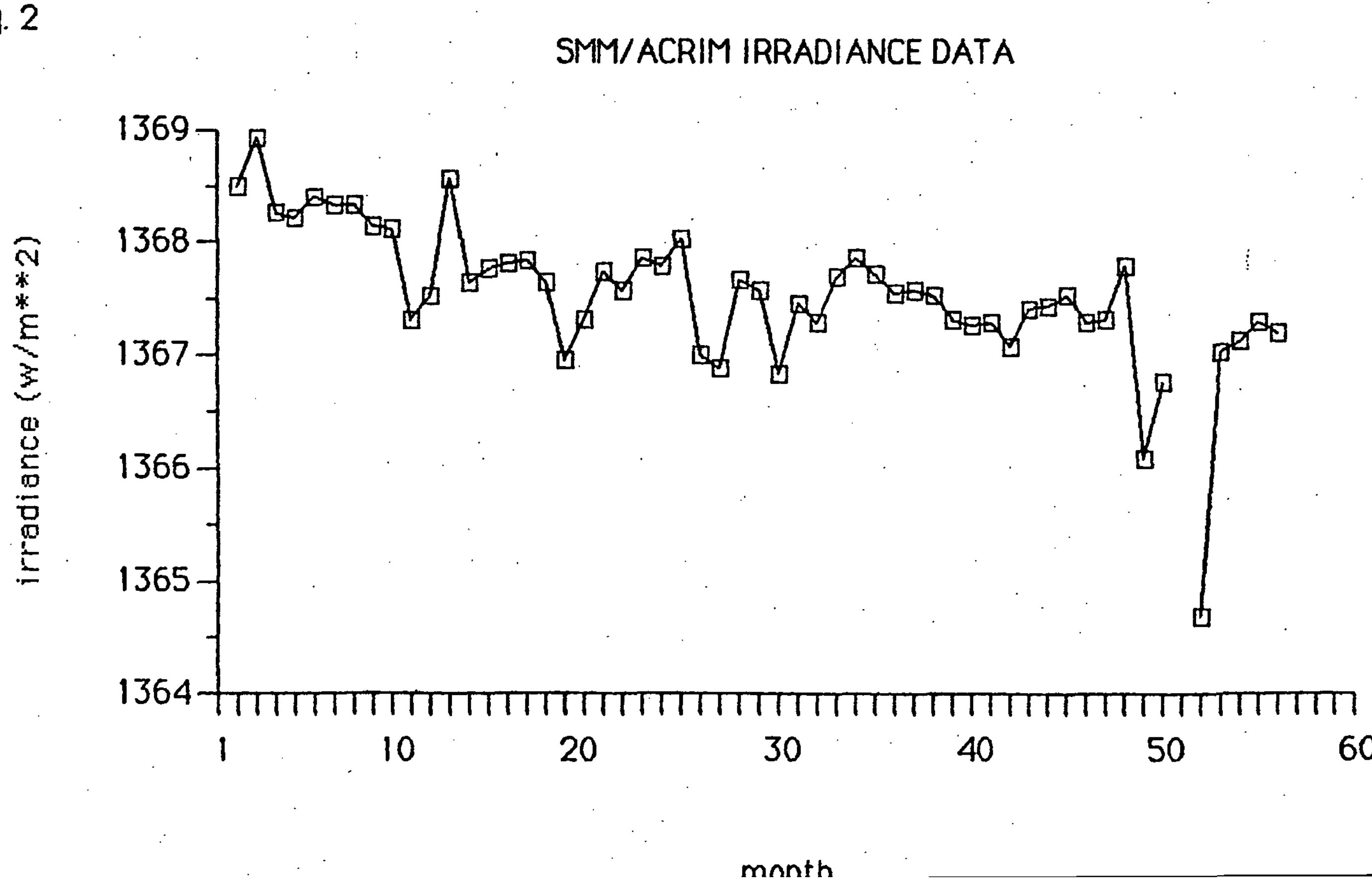

SMM/ACRIM IRRADIANCE DATA
irradiance (w/m**2)
1364
1365
1366
1367
1368
1369
1
10
20
30
40
50
60
month

Fig. 3

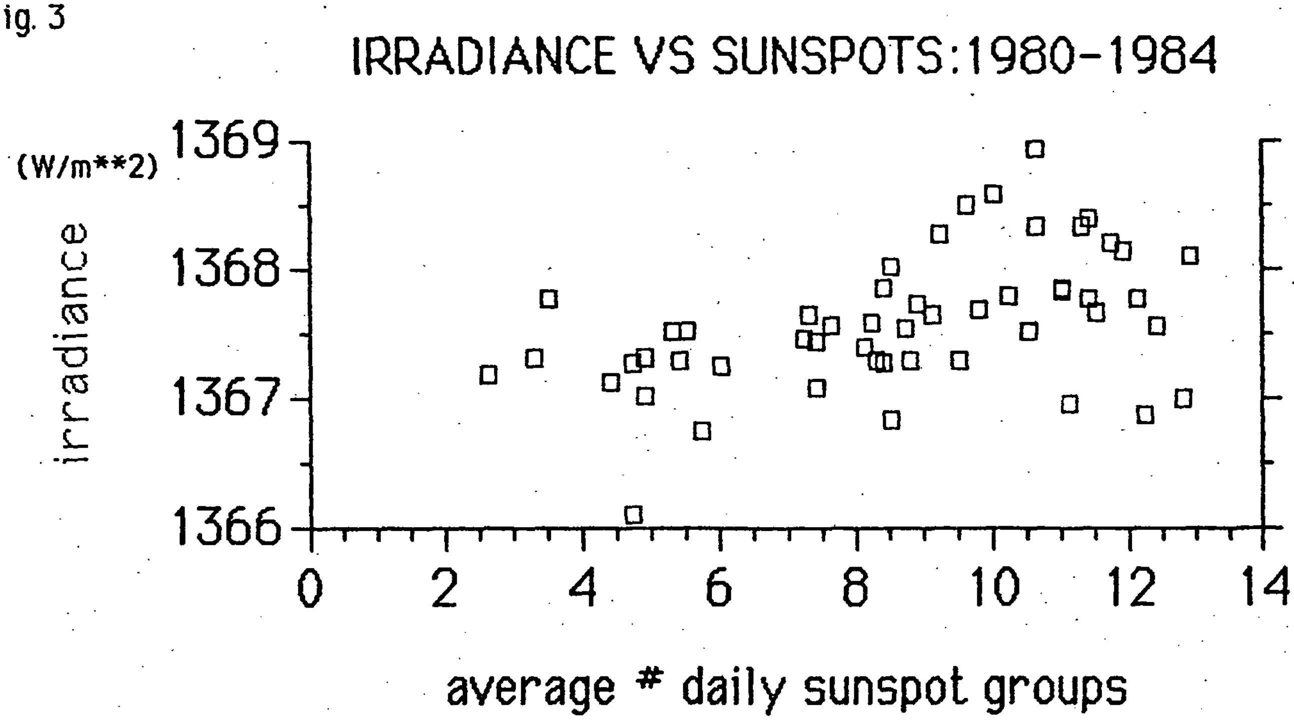

IRRADIANCE VS SUNSPOTS:1980-1984
(W/m**2)
irradiance
1369
1368
1367
1366
0
2
4
6
8
10
12
14
average # daily sunspot groups

Fig. 4

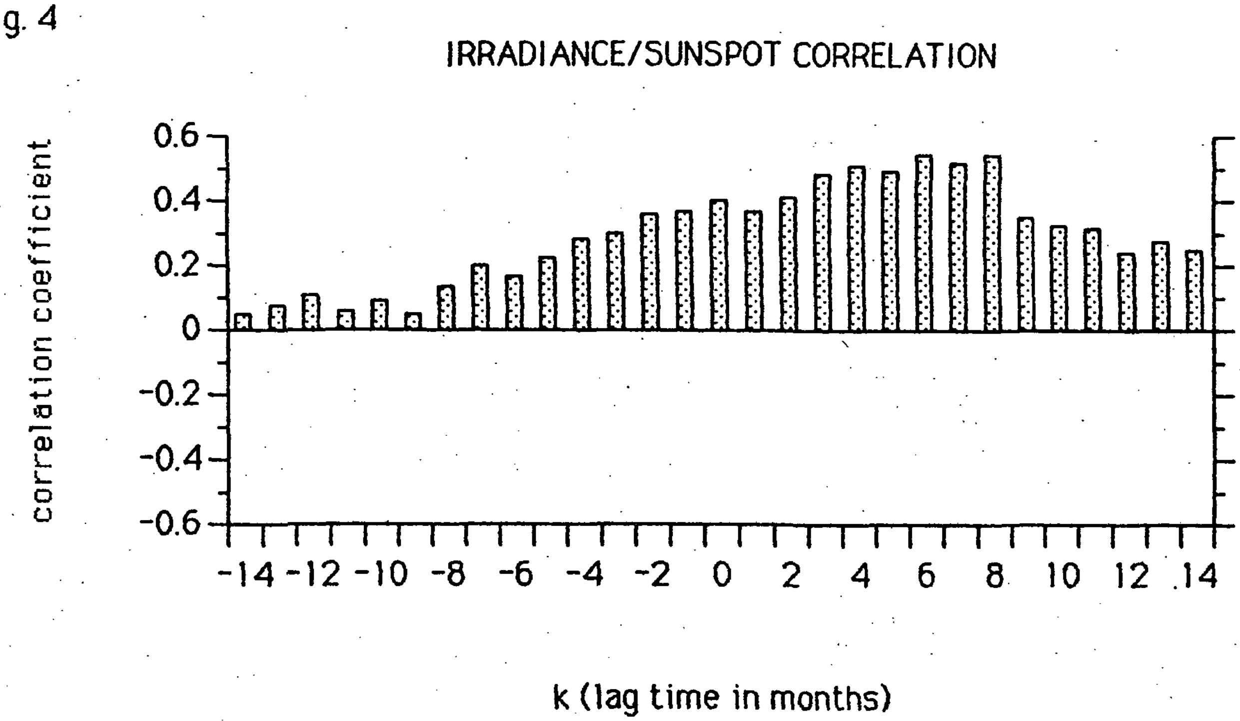
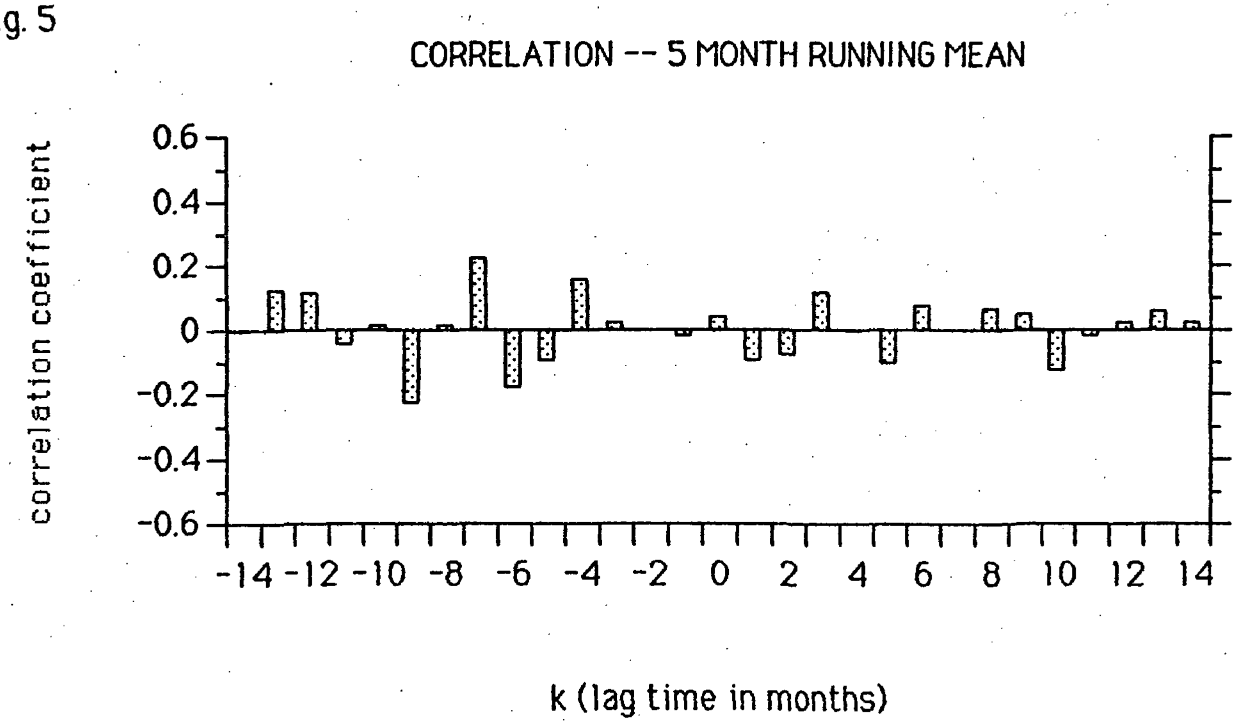

IRRADIANCE/SUNSPOT CORRELATION
correlation coefficient
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14
k (lag time in months)

Fig. 5


CORRELATION -- 5 MONTH RUNNING MEAN
correlation coefficient
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14
k (lag time in months)